Did biological activity in the Ionian Sea change after the Eastern Mediterranean Transient? Results from the analysis of remote sensing observations

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[1] The possible impact of the Eastern Mediterranean Transient (EMT) on the autotrophic biomass distribution has been investigated through a detailed analysis of remote sensing observations on a basin scale. Since the EMT effect was circumscribed in time, satellite data from Coastal Zone Color Scanner (CZCS) and Sea-viewing Wide Field-of-view Sensor (SeaWiFS), relative to the pre- and post-EMT period, respectively, were utilized for the study. The results of the analysis demonstrate that the changes in the circulation of the eastern Mediterranean Sea did not affect the general patterns of biomass distribution in the basin. The chlorophyll \(a\) fields at the surface were substantially similar in the CZCS and SeaWiFS periods, showing similar spatial patterns and only a slight difference in the timing of the main events. On the other hand, in the SeaWiFS period a recurrent and large patch of chlorophyll \(a\) was detectable in the northwestern Ionian Sea. The analysis of existing data supports the possibility that this new structure is the result of changes related to the EMT, though the observed subregional enhancement of biomass occurred only in an area where concurrent factors such as doming and convection played a synergistic role with the EMT-induced changes.

INDEX TERMS: 4275 Oceanography: General: Remote sensing and electromagnetic processes (0689); 4815 Oceanography: Biological and Chemical: Ecosystems, structure and dynamics; 4805 Oceanography: Biological and Chemical: Biogeochemical cycles (1615); KEYWORDS: Mediterranean Sea, CZCS, SeaWiFS, phytoplankton dynamics


1. Introduction

[2] In the last decades, several studies demonstrated that the environment of the Earth is changing, though the time and spatial patterns of those changes are poorly known [Eckmann, 1994]. There are evidences that marine ecosystems respond to the environmental modifications by altering and adapting their structure and functioning [e.g., Karl et al., 2001; McGowan et al., 1996; Reid et al., 1998].

[3] Synoptic data obtained from space at high frequency represent an invaluable resource of information to monitor, characterize and predict the effect of climate changes on the relevant aspects of ecosystem dynamics. Estimates of surface chlorophyll concentration and primary production derived from remotely sensed Ocean Color data do in fact provide a first-order view of the response of the phytoplanktonic community to environmental changes, though satellite data time series should be long enough to encompass the timescale of the supposed climate change.

[4] Only two significantly long time series of remote sensing data in the visible region of the spectrum are available to date: those generated by the CZCS (from 1979 to 1985) and those generated by the SeaWiFS (from 1997 to present).

[5] Previous attempts to compare CZCS and SeaWiFS data were performed in the Southern Ocean [Moore and Abbott, 2000] and in the Alboran Sea [Garcia-Gorriz and Carr, 1999] demonstrating the feasibility of such studies. In particular, in the former paper the comparison was based on an accurate analysis of different algorithms for atmospheric correction and for chlorophyll retrieval. In addition the International Ocean Color Coordinating Group (IOCCG) carried out several efforts to make the different ocean color
data consistent and concluded that the retrieved variables (e.g., biomass concentration) are comparable, provided that a good validation with in situ data is available [JOCCC, 1999].

[6] One of the sites recently affected by a large-scale fluctuation in thermohaline dynamics to be related with climate variability, which caused a visible impact also on the distribution of chemical properties, is the eastern Mediterranean Sea. Observations conducted in winter 1995, and during the following years showed that significant changes were occurring in the circulation of the eastern Mediterranean. The event was named Eastern Mediterranean Transient (EMT). The prior to EMT thermohaline circulation involved only one deep water formation zone in the south Adriatic Sea, with the whole deep thermohaline cell of the EMED, comprising the Ionian and the Levantine basins, being driven by this process [Roether et al., 1996].

[7] The new observations indicated that the Cretan/ Aegean Sea had become an additional driving engine of the intermediate and deep circulation of the EMED, with the CIW (Cretan Intermediate Water) and the CDW (Cretan Deep Water) spreading out from the Aegean Straits region into the basin interior. Because of the high density of the CDW ($\sigma_0 > 29.1$) the bottom layer of a vast area of the eastern Mediterranean was occupied by this new water mass, which displaced the older Eastern Mediterranean Deep Water (EMDW), thus rising the isopycnal surfaces and the nutricline by several hundred meters [Klein et al., 1999].

[8] The effects of this evident uplift of the nutricline on the biological activity of the basin are still poorly known. Civitarese and Gacic [2001] analyzed the impact of the EMT in the southern Adriatic, but could not give a definitive answer. As a matter of fact, they showed, through the comparison of nitrate concentrations in the intermediate layer, that during the years 1987–1999 new production had not increased significantly.

[9] In general, in situ data collected both in the years preceding [Rabitti et al., 1994] and following the EMT [Boldrin et al., 2002] confirm the oligotrophic regime of the area, with surface values of chlorophyll concentration ranging from 0.01 to 0.1 mg/m$^3$. However, the measurements conducted after the onset of the EMT are limited in time and space and therefore preclude an assessment of the prior to EMT stationary functioning of the basin.

[10] Stratford and Haines [2002] analyzed the results of a coupled physical-biogeochemical GCM for the Mediterranean, and suggested that the EMT might have changed the biological production of the basin by no more than 20–30%. According to their analysis, even if the depth of the nutricline had changed, only anomalously deep winter mixing events would have allowed significant nutrient transport from the uplifted nutricline to the photic zone.

[11] It is worth noting that the effect of the EMT may have been not macroscopically visible; that is, the rising of the nutricline may have not resulted in a temporally and spatially diffuse increase in phytoplankton concentration, but merely in episodic and locally relevant phenomena of chlorophyll enhancement, which could have been detected only with systematic, highly temporally resolved observations of the whole basin.

[12] In fact, as pointed out by Stratford and Haines [2002], an increase in the vertical transport of nutrients cannot occur anywhere in the basin, because of the subsurface circulation. For this reason, the EMT impact might have altered just the spatial distribution of biomass peaks.

[13] Because of the relatively restricted time span between pre-EMT and the present phase, a comparative analysis of remotely sensed properties becomes a very useful tool to assess any significant changes caused by the EMT, although only in the surface layer of the water column.

[14] The Transient was reasonably circumscribed in time. Thus a comparison between pre-EMT status and the present condition should permit a first-order quantitative assessment of any hypothesized changes in the trophic dynamics of the basin.

[15] The pre-EMT satellite observations were thoroughly analyzed by Antoine et al. [1995] (hereinafter referred to as A95). The authors described for the first time the chlorophyll $a$ distribution in the eastern Mediterranean Sea [EMED] utilizing remote sensing data. They computed the pigment concentration for the first optical depth using CZCS imagery and the primary production of the area, following “ad hoc” procedures [Bricaud and Morel, 1987; André and Morel, 1991; Antoine and Morel, 1996]. Because of the small number of available CZCS scenes, the analysis was performed on the climatological scale, producing seasonal maps of the years 1979–1985. Their results substantiated the view of EMED being extremely oligotrophic, with only a few zones where biomass enhancement episodically occurs, i.e., a weak spring bloom in the northern Ionian Sea and a higher biomass concentration inside the Rhodes Gyre in April and March, respectively.

[16] As for the post-EMT period we used the SeaWiFS data available since 1998. The biomass fields retrieved by satellite were then compared at basin and local scale and the time series of different regions of interest were analyzed to detect any patterns in the spatial and temporal distributions of autotrophic biomass to be compared with the pre-EMT CZCS existing information.

[17] It is worth reminding that the satellite data represents a very powerful tool in the assessment of the sea surface chlorophyll $a$ spatial and interannual variability, though limited by the specific coverage of the sensors and by the cloud coverage. Therefore the comparison between two time series of ocean color, twenty years apart, should allow verifying or falsifying the hypothesis that the EMT produced, because of the uplift of the nutricline by several hundred meters, a detectable biological response in the epipelagic layer. The implicit assumption is that because of the demonstrated exceptionality of the EMT on the pluridecadal timescale, the CZCS years were representative of the prior to EMT stationary functioning of the basin.

[18] The observed differences between the two periods were also investigated by means of ancillary in situ data and model-derived reconstruction of the hydrographic dynamics and the trophic regime of the basin. A hypothesis of the effect of the EMT on the biological dynamics of the basin was then discussed, especially for the region where the main differences are observed. We did not try to provide a full and complete explanation of the observed variability, which would have required more detailed in situ information, which is unfortunately lacking. However, we are convinced that the remote observations represent a necessary step to
assess variations and to suggest further analyses and possible model/data combinations.

2. Materials and Methods

2.1. CZCS Data

[19] Since the A95 maps are monthly averages over the whole CZCS period, we systematically analyzed the single scenes, using CZCS data available via WWW (http://me-www.jrc.it/ocean/ocean.html) from the Ocean Color European Archive Network (OCEAN) Project, conducted by the EU-Joint Research Center (JRC-Ispra). In the framework of this project, the CZCS data set was reprocessed and made available (CZCS-JRC hereafter). The entire data series covers the period 1979–1985 and consists of 1072 images of the Mediterranean Sea.

[20] The data processing procedures were performed within the above mentioned project, on the basis of a reflectance model-based algorithm. In brief, the Rayleigh correction utilized a multiple scattering approach and introduced atmospheric pressure and ozone concentration data in the computation. A marine aerosol correction using a pixel-by-pixel iterative procedure, allowed successive estimates of both the marine reflectance in the red spectral region (670 nm) and the Angstrom exponent, which links simple wavelength ratios to reflectance ratios. For case 1 waters, the relationship between marine reflectances and reflectance ratios at various wavelengths was derived from modeled calculations, while for identified case 2 waters it was approximated by applying empirical relationships derived from in situ measurements. The computation of the water constituents’ concentration was performed using algorithms based on blue/green (443/550 nm) reflectance ratios, for lower pigment concentrations, or on green/green (520/550 nm) reflectance ratios, for higher pigment concentrations. The relationships between pigment concentration and reflectance ratios were model-derived for case 1 waters, and empirically determined for case 2 waters. These algorithms are calibrated to retrieve pigment estimates in the first optical depth, which is the inverse of the attenuation coefficient. The attenuation coefficient itself depends, aside from the optical properties of the seawater, on the quantity of suspended and dissolved material present in the upper layer. Therefore the satellite-derived pigment concentration is the optically weighted integral of the biomass present in the first optical depth. In our region, the Mediterranean Sea, this depth ranges from few meters in high productive waters to 40–50 m in ultra-oligothrophic waters. Finally, individual images of pigment concentration were remapped on a standard 1 km pixel grid for each available day (see Sturm et al. [1999] for additional details).

2.2. SeaWiFS Data

[21] High-resolution picture transmission (HRPT) SeaWiFS data were collected by the receiving station HROM at the ISAC-CNR (formerly IFA-CNR), Rome, Italy. All the SeaWiFS passages relative to the period 1998–2001 were extracted from ISAC archive and processed up to level 2 to obtain Normalized Water Leaving Radiance ($L_{\text{sw}}$) and Remote Sensing Reflectance ($R_{\text{rs}}$) maps for the five available visible bands (412, 443, 490, 510 and 555 nm) using the SEADAS software v.4.0B [Baith et al., 2001]. To obtain chlorophyll estimates for the eastern Mediterranean Sea, we applied the NL-DORMA [D’Ortenzio et al., 2002] algorithm, specifically retrieved for the SeaWiFS chlorophyll estimates in the Mediterranean Sea (see D’Ortenzio et al. [2002] for details). Satellite data were remapped on a 1 km resolution equi-rectangular projection in the regions of interest, using the University of Miami Display Software Package (DSP). Final maps were flagged applying all the 24 masks provided by SEADAS [Baith et al., 2001]. Finally 2745 maps of Mediterranean Sea were available for further analysis.

2.3. Satellite Data Intercalibration

[22] The chlorophyll data used in this work come from two different remote sensors (SeaWiFS and CZCS) and three different procedures [D’Ortenzio et al., 2002; Antoine et al., 1995; Sturm et al., 1999], which raises problems of intercomparison.

[23] To the best of our knowledge, no comparison between CZCS-JRC and CZCS-A95 data was ever performed. Hence, to verify the consistency of the two different procedures, we compared the values reported in the Table 3 of A95 and the chlorophyll values as derived by the CZCS-JRC data set, for the same areas and time intervals. This was accomplished by means of the Web interface developed by the JRC group, which allows downloading each scene individually.

[24] Recently, Bricaud et al. [2002] performed a quantitative analysis of ocean color data on the Mediterranean Sea from CZCS, SeaWiFS, Ocean Color and Temperature Scanner (OCTS) and Polarization and Directionality for the Earth’s Reflectances (POLDER). They divided the basin in 13 regions and calculated the temporal averages of chlorophyll concentration for each region. In general the behavior of the data from the different sensors is similar, even if some discrepancies are evident. In particular, SeaWiFS-derived chlorophyll concentrations display an overestimate in the oligotrophic regions of the basin.

[25] Using an extensive Mediterranean data set of biophysical and biological data, D’Ortenzio et al. [2002] compared a set of the most used SeaWiFS chlorophyll algorithms and confirmed that an overestimate of biomass occurs systematically in Mediterranean. Therefore they proposed a new temporary regional algorithm (SeaWiFS-NL-DORMA) derived from the tuning of the standard NASA algorithm to the Mediterranean region to retrieve SeaWiFS chlorophyll concentration.

[26] All the above leads to the conclusion that the estimates of chlorophyll derived by the three data sets (SeaWiFS-NL-DORMA, CZCS-A95, and CZCS-JRC) are the best available for the Mediterranean Sea. Obviously a certain degree of uncertainty still remains, mainly in the CZCS data, which were validated with a reduced set of in situ match-up points. Nevertheless, we will show that relevant questions of this study may be answered notwithstanding those uncertainties, thus making this comparative analysis sound.

3. Results

[27] The biomass fields retrieved by satellite were compared at basin and local scale and the time series of different
Table 1. Comparison Among Various Chlorophyll Determinations in the Eastern Mediterranean Sea From CZCS Satellite and in Situ Surface Data Retrieved From the Literature

<table>
<thead>
<tr>
<th>Region</th>
<th>Period</th>
<th>CZCS-A95, mgChl/m³</th>
<th>CZCS-JRC, mgChl/m³</th>
<th>In situ, mgChl/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southeast Lev</td>
<td>July, Dec., April</td>
<td>0.00–0.05</td>
<td>0.03–0.07</td>
<td>0.03–0.07</td>
</tr>
<tr>
<td>Northeast Lev</td>
<td>June, July, Sept.</td>
<td>0.05–0.1</td>
<td>0.03–0.04</td>
<td>0.05–0.1s</td>
</tr>
<tr>
<td>Eastern Lev</td>
<td>April</td>
<td>0.00–0.05</td>
<td>0.03–0.07</td>
<td>0.03–0.05</td>
</tr>
<tr>
<td>Eastern Lev</td>
<td>July</td>
<td>0.00–0.05</td>
<td>0.00–0.03</td>
<td>0.02–0.04</td>
</tr>
<tr>
<td>Cyprus eddy</td>
<td>Feb.</td>
<td>0.00–0.05</td>
<td>0.10–0.25</td>
<td>0.15–0.25</td>
</tr>
<tr>
<td>Cyprus eddy</td>
<td>May</td>
<td>0.00–0.05</td>
<td>0.00–0.03</td>
<td>0.04</td>
</tr>
<tr>
<td>Cyprus eddy</td>
<td>Sept., Nov.</td>
<td>0.00–0.05</td>
<td>0.00–0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Lev + Ion</td>
<td>summer</td>
<td>0.1</td>
<td>0.05–0.08</td>
<td>0.09</td>
</tr>
<tr>
<td>Lev + Ion</td>
<td>year</td>
<td>0.1–0.3</td>
<td>0.1–0.2</td>
<td>0.14</td>
</tr>
<tr>
<td>Lev + Ion</td>
<td>June, July</td>
<td>0.05–0.1</td>
<td>0.00–0.06</td>
<td>0.1</td>
</tr>
<tr>
<td>Lev + Ion</td>
<td>Dec., Jan.</td>
<td>0.1–0.3</td>
<td>0.2–0.6</td>
<td>0.5–0.6</td>
</tr>
<tr>
<td>Lev + Ion</td>
<td>April</td>
<td>0.1–0.5</td>
<td>0.1–0.8</td>
<td>0.5–1.0</td>
</tr>
<tr>
<td>Lev + Ion</td>
<td>Aug.</td>
<td>0.00–0.05</td>
<td>0.00–0.05</td>
<td>0.02</td>
</tr>
<tr>
<td>Lev + Ion</td>
<td>Nov.</td>
<td>0.00–0.05</td>
<td>0.00–0.06</td>
<td>0.05–0.1</td>
</tr>
<tr>
<td>Aegean Sea</td>
<td>extrema of year</td>
<td>0.05–0.3</td>
<td>0.06–0.32</td>
<td>0.01–0.18</td>
</tr>
<tr>
<td>South East Cyprus</td>
<td>Sept.</td>
<td>0.00–0.05</td>
<td>0.00–0.03</td>
<td>0.03–0.04</td>
</tr>
</tbody>
</table>

*Antoine et al. [1995] and JRC data sets.

The regions of interest were analyzed to detect any patterns in the spatial and temporal distributions of autotrophic biomass. As already pointed out, the ocean color sensors provide information only on the first layer of the water column. In the Mediterranean Sea, where a Deep Chlorophyll Maximum (DCM) is a peculiar characteristic of the basin, the satellite estimates cannot retrieve entirely the biomass content of the water column. On the other hand, when the right conditions are present (i.e., nutrients availability in the upper illuminated layer), the increase in biomass occurs at or close to the surface, where the satellite is able to detect it. In other words, even if the ocean color data do not provide the total chlorophyll content in the water column, they are excellent indicators of the biological activity.

### 3.1. Chlorophyll Distribution in the EMED Derived by Different Procedures and Platforms

[28] As mentioned above, the A95 work was aimed at the characterization of the Mediterranean’s seasonal variability in biological properties, based on climatological maps derived from the CZCS sensor, after an “ad hoc” data processing (see A95 for details). To take advantage of the single scenes of the OCEAN archive we first checked their consistency with the former maps, by comparing the chlorophyll values derived by the two procedures after averaging the Ocean scenes as in A95. The result is reported in Table 1, and shows a general agreement, hence CZCS-JRC and CZCS-A95 may be taken as interchangeable.

[29] To conduct a more detailed comparison of the chlorophyll a fields at basin scale, we produced monthly climatological maps of SeaWiFS (1998–2001) images (Figure 1a) and compared them with the CZCS-A95 (1979–1985) available on the WWW (http://www.obs-vlfr.fr/jgosf2/modelisation/mediterr.htm) (Figure 1b).

[30] The comparison of the two data sets on the seasonal timescale shows that the dominant features of the area are conserved for most of the year and for a large area of the basin, confirming the well-known oligotrophy and ultra-oligotrophy of the region (surface chlorophyll range 0.05–0.1 mg/m³).

[31] In more detail, the zonal west-to-east gradient in chlorophyll concentration is very similar in the two data sets with the lowest values of chlorophyll concentration below 0.08 mg/m³ occurring in the eastern part of the basin. Also the latitudinal gradient, with chlorophyll decreasing from north-to-south is very similar. As a result, the Levantine area is the region displaying the lowest values of autotrophic biomass with its minima to the south of the 35th parallel.

[32] However, fundamental differences between the two time series can be detected, both in the spatial distribution of the relevant features and in the timing of regional events of biomass increase. In the A95 analysis (see their Figure 2) maxima of chlorophyll concentration are observed in June–July in the Ionian and Levantine basins, while the lowest values are reported in spring. The authors suggest, as an explanatory cause, that the onset of the thermocline in March–April would lead to a biomass increase in late spring and early summer when the upper layer is well stratified. However, no additional proof is given to support the above mentioned hypothesis.

[33] This seasonal pattern seems to be reverted in the SeaWiFS years, when chlorophyll increase at basin scale is observed in late winter-spring, whereas the lowest values of biomass are detected during summer. In other words, the spatial distribution of biomass in the eastern Mediterranean exhibits a two-state modality, switching from a general oligotrophic regime (chlorophyll concentrations in the range 0.05–0.1 mg/m³) in summer and autumn to a less oligotrophic situation (surface chlorophyll concentrations in the range 0.2–0.3 mg/m³) in late winter to early spring. The shift between the two modes occurs in October and April when biomass distribution and values are very similar. These two months could then be considered as the two nodes in the transition from one trophic state to the other.

[34] The presence of both a latitudinal and a zonal gradient in the biomass distribution results also from the simulations conducted by Crise et al. [1999], from which they inferred that the zonal gradient is mostly due to the progressive loss of surface nutrients from west to east because of the biological pump. However, they did not
address the issue of seasonality, which is well depicted by the SeaWiFS time series.

More interestingly the SeaWiFS monthly maps show that, embedded in the widespread biomass increase at basin scale in late winter to spring, there are specific areas at subbasin scale displaying an enhanced response. In particular, a significant enhancement of surface biomass offshore of the eastern Calabrian coast (northern Ionian Sea) is observed in the SeaWiFS years in March and April, with values up to 0.4–0.5 and 0.2–0.3 mg/m$^3$, respectively, which is a novel feature for the basin. In fact, only a slight, general and diffuse increment in biomass in the northern

![Figure 1a. Monthly averaged maps of the SeaWiFS-derived chlorophyll concentration over the eastern Mediterranean.](image)
Ionian Sea in April is visible in the CZCS years, as reported also by Antoine et al. [1995].

[36] In the Rhodes Gyre region, where there is an active cyclonic structure [Ozsoy et al., 1993; Sur et al., 1993] a moderately eutrophic regime is present (average values 0.2–0.3 mg/m³) in the climatological March. Several studies were conducted in this region in the past years [Ediger and Yilmaz, 1996; Yilmaz et al., 1994] showing that the increment in chlorophyll may be directly related to the strong vertical mixing because of the dense water formation.
observed in the gyre. Maxima are observed in March, confirming that the increase in biomass begins when the mixing event is already finished and the water column starts to stratify. The structure is present also in the CZCS maps and a detailed study of the bloom is discussed in A95.

[37] To briefly summarize the relevant information deriving from the analysis of climatological maps, we conclude that the two data sets are consistent, displaying comparable absolute values of chlorophyll concentration and very similar spatial patterns for most of the area. Indeed, there are differences concerning the timing of the spring bloom (and its decay) and the presence in the SeaWiFS period of a biomass enhancement in the Ionian Sea as compared with the CZCS data.

[38] In order to better investigate the reasons for those differences, and their reliability, we carried out a detailed analysis on a daily basis, looking at the single images, thus allowing the detection of even sporadic events of chlorophyll augmentation.

3.2. EMED Blooms

[39] We focused our observations on three regions of the EMED: the northern Ionian and Rhodes Gyre region, where the biological signal displays the highest values, and the eastern Ionian Sea, as an example of oligotrophic conditions, thus representative of a large part of the EMED. The choice of the eastern Ionian Sea region is also based on considerations relative to the supposed effect of the EMT on the basin. In fact, according to the spatial relocation of the nutricline as reported by Klein et al. [1999], the eastern Ionian should have been less affected by the EMT.

[40] For the selected regions, we extracted a 20 × 20 pixel box (22 km side) from each daily scene and averaged every pixel in the box that passed the exclusion criteria described above (sections 2.1 and 2.2). The exact location of the boxes, relative only to the Ionian Sea, is shown in Figure 2. In addition, for the three regions of interest we extracted and calculated the net heat flux derived by the NCEP data. The time series of net heat fluxes were produced integrating over each day starting from 1 October to 1 October of the following year, in order to calculate the integrated net heat flux relative to each year. Finally, the two parameters (chlorophyll concentration and integrated net heat flux) were plotted as a function of time (Figure 3) in order to investigate the relationship between the atmospheric forcing and the occurrence of the phytoplankton blooms.

[41] The rationale for conducting a simultaneous analysis of the surface chlorophyll content and the atmospheric forcing resides in the evidence that, as also noted by Stratford and Haines [2002] on the path of Gran [1931] and Sverdrup [1953], the preconditioning mechanism to make the internal nutrient pool available for the autotrophs in the photic zone of the open sea must be the winter convective mixing. Therefore the analysis of the atmospheric forcing would allow determining to what extent and where any observed variability of the EMED biomass field, could be attributed to the enhanced vertical transfer of nutrients because of convection. In addition, the tight correspondence of the features in the Rhodes Gyre region for both periods, confirm that systematic errors due to the use of two different sensors are minimal, thus supporting a posteriori the validity of the comparison.

3.2.1. Rhodes Gyre

[42] From the analysis of the climatological maps in the two different periods, the Rhodes Gyre Bloom (RGB) appears as a permanent feature of the basin, since the surface biomass is generally higher than the surrounding area for most of the year and in both the data sets. Then, the RGB confirms that the two data sets reproduce quite well the presumably persistent dynamics of the site and are thus comparable.

[43] The SeaWiFS time series at daily resolution exhibits a great interannual variability. A bloom appears in March–April 2000 with relatively high values of chlorophyll (0.4–0.5 mg/m³) and a great spatial extension (Figure 4). In 2000 the bloom starts in mid-March, even if an enhanced biomass occurs in the region in early March (chlorophyll values ~0.3 mg/m³), and lasts until early April. A minor chlorophyll enhancement occurs in 1998 (chlorophyll values ~0.3 mg/m³) in late March, but not in 1999 when the region appears totally oligotrophic (maximum chlorophyll value ~0.2 mg/m³), as the rest of the basin. The variability of the RGB is evident also in the CZCS data, but with a quite regular biomass increase in spring or late winter, and no evidence in the time series of a 2000-like bloom, except in 1985, when the RGB with the shape and features of the SeaWiFS year 2000 is evident in three CZCS scenes (see also A95, Plate 1).

[44] In the RGB region, the correspondence between the integrated heat fluxes and the increase in biomass is also evident. Only when strong atmospheric events occurred (i.e., winter 1999–2000 with peaks of integrated heat fluxes reaching the value of ~0.5 × 10⁷ J/m²) a biomass bloom took place. Several studies in the past investigated the interaction between strong cooling events and phytoplankton response [Yilmaz and Tugrul, 1998; Ediger and Yilmaz, 1996; Napolitano et al., 2000] in the RGB. In particular, Napolitano et al. [2000], using a five-compartment physi-
cal-biological 1-D model forced with realistic heat fluxes, analyzed the effect of the cooling event on the biomass field, and reproduced very well the time course of the chlorophyll \( a \) increase, though with higher values than those retrieved in A95.

[45] The correlation between heat fluxes and phytoplankton response is fully confirmed by the combined analysis on the SeaWiFS and NCEP data, showing that the RGB is directly related to atmospheric forcing. Most of the interannual variability of the biomass field, evident in the time series, could be explained by the variability in the time series of heat fluxes.

[46] In conclusion, the results of the analysis of the remotely sensed data appear in agreement with the previous studies of the region, revealing a picture of the RGR bloom as a biological phenomena strongly related to the local dynamic structure (the gyre) and to the atmospheric forcing. Both time series display very similar responses after intense buoyancy loss, with the CZCS being much coarser in resolution respect to the almost continuous profile of the SeaWiFS time series (Figure 3).

3.2.2. Northern Ionian Sea

[47] An intense and large chlorophyll a patch offshore the eastern Calabrian coast is detectable in SeaWiFS images in early spring, with values reaching 0.6–0.9 mg/m\(^3\) (Figure 5a). Similarly to the RGB, the Calabrian Bloom (CB) shows great time variability in the three years we analyzed. However, it is almost always present in March and disappears in mid-April. In 1998 it starts in early April, in 1999 during the first days of March, while in 2000 it appears in mid-March. In 1999 it extends from the coast to a distance of at least 150 km, with a fairly uniform chlorophyll distribution until its decay a few weeks later, with the exception of a narrow band closer to the coast where the chlorophyll concentration remains always high. Considering the narrow shelf (see Figure 2), the length scale and the absence of large rivers, the structure is clearly related to an open ocean event. This is much more evident in 1998 when the highest chlorophyll a values are centered approximately 100 km offshore.

[48] No evidence of this structure exists in the CZCS data, even if the number of the CZCS cloud-free scenes in the period of interest is quite large: a careful visual inspection was performed, displaying all the available single scenes and checking out not only the absolute values of chlorophyll estimates but also biomass gradients in the region. Antoine et al. [1995] reported a slight, general and diffuse increment in biomass in the northern Ionian Sea in

Figure 3. (continued)

![Figure 3](image-url)
April [Antoine et al., 1995, Plate 1], but the pattern was definitely different with a clear gradient decreasing offshore.

[49] The analysis of the NCEP data (Figure 3) reveals that the increase of biomass is related to strong events of heat loss in the period just preceding the bloom, which is a typical pattern for the onset of plankton bloom in late winter to early spring in temperate regions [Longhurst, 1998], as we noted also for the RGB. The correlation between the two events suggests that the timing of this ocean-atmosphere coupling determines also the time when the bloom occurs in the three years studied. In addition, the magnitude of the biomass enhancement seems to be directly dependent on the intensity of the atmospheric events: the highest values of chlorophyll are observed in year 2000 when the heat loss reaches the maximum value observed in the studied years; on the other hand, when the

Figure 4. Selected images of SeaWiFS-derived chlorophyll concentration over the Rhodes Gyre region for the year 2000.
Figure 5. Selected images of SeaWiFS-derived chlorophyll concentration over the Calabrian Bloom region for the years 1998, 1999, and 2000.
Figure 5. (continued)
atmospheric forcing is below the value of $-0.3 \cdot 10^9 \text{ J/m}^2$ (i.e., in 1998) the bloom appears less pronounced. Even if no studies similar to those conducted in the Rhodes region are available, one could argue that the dynamics of the two blooms is similar. Strong atmospheric events force deeper convection in a cyclonic structure such as the one reported for the northern Ionian Sea since 1998 [Manca, 2000] and produce a larger vertical transport of nutrients in the photic layer, allowing an enhanced plankton growth. The above description is also confirmed by Boldrin et al. [2002], who present data of a sediment trap located in the region of the CB, through the years 1997–1999. The peak of total mass flux in 1998 [Boldrin et al., 2002, Figure 8] occurs in late April, i.e., about 15 days after the decay of the CB, substantiating the presence of a high biological activity in the surface layer.

The scarce number of observations of the CZCS sensor and the relatively short duration of the phenomena (the maximum duration was 30 days in 1999) do not permit to absolutely exclude its occurrence in the CZCS period. On the other hand, the evidence of the structure is very clear in all the SeaWiFS years and not in the CZCS years, notwithstanding similar atmospheric forcing in the area. In Section 5.2 we will comment in more detail on the possible causes of the bloom, also considering the nutrient in situ data, and we will try to investigate on the potential role of the EMT in the onset of the CB.

### 3.2.3. Eastern Ionian Sea

In this region the phytoplanktonic biomass in spring slightly exceeds the background concentration levels observed during the rest of the year. The region appears strongly oligotrophic with chlorophyll values rarely greater than 0.2 mg/m$^3$ (see Figure 3c). The highest values are present, as already noted in the climatological maps, during the late winter and the early spring, while the lowest levels occur always in summer. In 1999 the biomass enhancement is more pronounced than in the other two SeaWiFS years analyzed in this study. The behavior of the chlorophyll time series appears similar for the SeaWiFS and for the CZCS, even if the seasonal signal is not very evident in the CZCS data.

The analysis of the NCEP-derived integrated heat fluxes in the region demonstrates that even in presence of strong cooling events (similar in magnitude to those observed in the RGB and in the CB) no signals are detectable in the satellite-derived chlorophyll time series. This suggests that a concurrent dynamic structure, such as, for example, a cyclone, contributes to the onset of eastern Mediterranean blooms.

### 3.3. In Situ Nutrient Profiles

Our analysis so far was based on remote sensing observations, which evidenced variations only in a relatively restricted area of the basin. As mentioned above this approach was the only feasible because of the lack of in situ data covering the two decades between the CZCS and SeaWiFS periods. Nevertheless, to investigate whether the reported uprising of the nutricline [e.g., Klein et al., 1999] could be considered a consistent feature of the late nineties in the Ionian Sea we compiled the available existing nutrient data for two sites, which had been sampled a few times over the last decades. Both are located on the western side of the Ionian basin, with the northern site being the area of the CB. To show the time trend of the nutricline we report here the nitrate profiles, notwithstanding the evidence that in some areas of the EMED phosphates appear to determine the carrying capacity of the pelagic system [Thingstad and Rassoulzadegan, 1999]. The reason for doing this is two-fold: 1. The phosphate and nitrate profiles display the same trend, with a much higher scatter in phosphate data because of the very low concentrations typical of the EMED even at depth (max 0.25 mmol/dm$^3$); 2. our aim is to determine whether the CB is associated with a different vertical distribution of any essential nutrient, being the occurrence of the CB in itself a proof that any nutrient limitation had been partially relaxed. The sampling location areas are reported in Figure 2, whereas nitrate profiles for the upper 500 m are shown in Figure 6, which includes also the list of the cruises which they belong to. The discrete data have been fitted with a spline interpolator to better visualize the profile. At both sites the progressive uplift of the nutricline is evident, especially for what the 150–500 m layer concerns. Even more relevant, is the resulting increase in the subsurface concentrations. At 150 m nitrites are, on average, 3 mmol/dm$^3$ higher in the nineties than they were until the end of the eighties. It is also worth noting that the profiles cover similar seasons and that, notwithstanding their very reduced number, they span over most of the western Ionian. We will return to the implications of the change in the subsurface concentrations next.

### 4. Discussion

#### 4.1. Temporal and Spatial Resolution

The pixel resolution is practically the same for the CZCS and SeaWiFS (1.1. km), though the area covered by the two sensors for each scan is significantly different, the one covered by CZCS being narrower. Figure 7 shows the frequency of the observations for the two different sensors. As a matter of fact, the “true” SeaWiFS daily coverage of the EMED area reduces data losses because of cloud cover and allows a better tracking of oceanic processes. By contrast, the lower frequency of the CZCS passages produced a much smaller data set, which prevented in many circumstances a satisfactory description of the in situ dynamics.

On the other hand, the general features of the basin are preserved in the two data sets, and the resulting picture, as we remarked in the previous sections, is that of an ultra-oligotrophic basin with a slight biomass increase in spring, enhanced in particular areas by local events.

The algorithms for atmospheric correction and chlorophyll retrieval for both sensors have been developed and tested specifically for the Mediterranean Sea (see section 2) and this accounts for the very satisfactory match between the biomass concentrations in the corresponding regions, which makes us more confident on the consistency of the absolute values in retrieved data.

In other words, even if we did not create an unique time series of ocean color sensors (i.e., the same algorithms for atmospheric correction and chlorophyll retrieval), which, by the way, was out of the aim of this paper, we demonstrated that the two data sets are comparable and, consequently, that not all the differences in the
surface biomass field can be accounted for only by the different frequency of observation of the two sensors. For example, CZCS scenes show the RGB sporadically. This might certainly be due to the infrequent sampling of the platform, which might have missed the bloom at its peak. But, a careful observation of the scattered chlorophyll values at the site (Figure 3a) clearly shows an increase in their values in coincidence with intense events of integrated heat loss, very similarly to what occurs in the SeaWiFS time series. Then we conclude that the characteristics of the RGB are very similar in the two analyzed periods (1979–1985 CZCS; 1998–2001 SeaWiFS) and therefore that it is a permanent and peculiar feature of the EMED. Also, we can say that, as expected, the EMT

![Figure 6](image1.png)  
**Figure 6.** Vertical profiles of nitrate for the two Ionian regions selected: (left) southwestern Ionian and (right) northwestern Ionian.

![Figure 7](image2.png)  
**Figure 7.** Density of the satellite observations over the eastern Mediterranean Sea: (left) SeaWiFS data and (right) CZCS- JRC data.
did not affect the physical dynamics of the structure and the consequent biological response.

[55] The case of the CB seems very different. In the SeaWiFS years we analyzed, the CB is always present and its dynamics is similarly related to the atmospheric forcing as for the RGB. The number of CZCS scenes available for this region is of the same order of magnitude as for the RGB area (or even higher; see Figure 2), but, as already pointed out, that structure never occurs. So we argue that the low frequency of observations of the CZCS sensor is not the cause of the different pattern observed in the western Ionian biomass field in the two periods. Therefore, in the limits of our analysis, it is possible to consider the CB a recent feature of the biological dynamics in the EME.

4.2. What is the Cause of the Observed Calabrian Bloom?

[59] In the previous sections a detailed analysis of the biomass fields from satellite was presented and a series of features regarding the biological dynamics of the basin was discussed. The analysis of the monthly mean maps revealed a substantial similarity in the EMED surface chlorophyll in the two periods considered. Changes in the intermediate and deep circulation of the basin and the different atmospheric forcing seem to not influence in an evident way the biological behavior of the EMED at basin and climatological scale. This is probably the most important result of our analysis: the biological compart (at least in the surface layer) of the EMED was in general unaffected by the dramatic change in the circulation and in the atmospheric forcing in the late 90s. However, the specific and more detailed investigation on particular regions (selected on the basis of the monthly mean maps analysis) revealed regional features that on one hand substantially confirmed the picture of an unchanged biological dynamics of the basin but on the other showed that some alterations were in act. In the first case, one can include the RGB, where no substantial changes are evident and where the atmospheric and dynamic couplings are capable to clarify most of the observed variability. Different appears the situation in the case of the CB. Following the arguments presented in the section 4.1, we demonstrated that the feature is a recent phenomenon, not present in the CZCS years. Changes in the atmospheric forcing in the area are not evident, then modifications in the physical dynamics of the basin have to be invoked to explain the different signal detected in the two analyzed periods. As highlighted in the introduction, the EMT is undoubtedly the most important event at basin scale affecting the physical dynamics of the region in the last years. However, to relate the CB to the EMT we need to verify what makes the region different from the rest of the Ionian basin and in particular to test a series of hypotheses regarding the mechanism producing the bloom.

[60] One of the expected responses of the system to the EMT is a change in its biogeochemistry, being the uplift of the nitrogen pool toward the surface one of the most important result of the EMT. How much closer to the surface must the nutricline go to drastically change the upward nutrient fluxes into the photic zone?

[61] We anticipated in the results section that winter convection is the main mechanism to pump nutrients from the subsurface pool to the upper layer, but we do not know how deep the convective layer could have been in the EMT years because we lack in situ observations at the proper time of the year.

[62] Therefore, to investigate on the vertical dynamics, we chose a simplified approach based on a 1-D model and realistic forcing conditions. We ran the widely used 1-D modulus of the Princeton Ocean Model [Mellor, 1998] forced with the NCEP heat fluxes and wind stress computed in the Ionian region for the year 1999, for which temperature and nutrients in situ profiles are available. Data come from the station I01 and S06 in winter (cruse SINAPSI-3), and S06 in spring (cruse EMTEC); see Figure 2 for the location of the stations. As initial conditions we used vertical climatological profiles of salinity and temperature (Figure 8) extracted from the Mediterranean Oceanic Data Base (MODB).

[63] The question we asked the model was a simple one. How deep could the winter mixing go and to what extent did the vertical transport alter the surface values of nutrient concentrations? We were not interested to accurately reproduce the mixed layer evolution in the area, but only to verify the intensity of the winter convection in a “mean” Ionian condition. The outputs of the model (Figure 9) demonstrate that, neglecting the lateral advection and the mesoscale and submesoscale structures, the atmospheric forcing in the area would have allowed a convective mixing down to 100 m, in the mean Ionian water column. Therefore only in the areas where the nutricline was above 100 m or where a less buoyant water column was present a significant transport could have occurred.

[64] The available data for 1999 show that the simulations of the mixed layer depth are in good agreement with the in situ data and that the nutricline was still below that depth, which might suggest that the response in the surface layer might have been absent. Only in the station I01 in winter a difference between in situ and simulated mixed layer depth is observable. In fact the station is located in a region where a cyclonic circulation was observed in the winter 1999 [Manca, 2000], i.e., in a hydrographic regime where the 1-D model, initialized with climatological hydrological profiles, does not work properly.

[65] It can be also noted (Figure 5) that the chlorophyll patch displays a quite homogeneous concentration and extends over the shelfbreak toward the coast. In other words it is not just centered on the structure described by Manca [2000]. Therefore we hypothesize the following: buoyancy fluxes during the years 1998, 1999, and 2000 were not strong enough to produce convection down to 120–150 m, i.e., the depth where nitrate concentration was high enough to alter the transport into the photic zone and sustain a greater biomass. The doming produced by the cyclonic circulation released the constraint in the northwestern area, but we suspect that the W-E asymmetry of the patch in respect to the location of the cyclonic structure is due to the interaction of the haline front that separates the coastal current from offshore waters and the cyclonic circulation, that very likely generates a strong ageostrophic component on the western rim of the structure, thus making the vertical transport more effective.

[66] In other words, our satellite observations confirm what the oceanographic community had already hypoth-
esized and Stratford and Haines [2002] analysis had anticipated: the EMT needed a concur of different processes, such as the uplift of the nitrate maximum, the buoyancy loss of the upper part of the water column and a dynamic scenario (doming, frontal divergence, etc) to be effective. The two latter events are quite typical of many regions of the global ocean and are, as we analyzed, the factors controlling the RGB, whereas the former event is the novel contribution of the EMT and explains, in our view, the absence of the CB during the CZCS years. In addition, modeling studies [Pinardi and Masetti, 2000] suggest that also during the CZCS years the circulation in the northwestern Ionian during winter and spring was cyclonic, thus substantiating the hypothesis that was the pre-EMT location of the nitrate maximum to prevent the occurrence of CB. Furthermore the observed reversal of the circulation has only recently been reported and its short life is supported by the wind pattern over the basin [Manca, 2000; Manca et al., 2002].

On the other hand, while in the late eighties there is a strong evidence of an anticyclonic circulation in the late summer [Malanotte-Rizzoli et al., 1997] at the beginning of the nineties all the observations converge in assessing that the circulation kept an anticyclonic rotation all year-round.

Then the question rises on what happened during the years when the SeaWiFS was not yet active and when the supposed change started. We addressed the questions again relying on remote sensing. Advanced very high resolution radiometer (AVHRR) data can contribute to investigate the interannual variability of the sea surface temperature (SST) distribution in the Ionian Sea in a period of time that goes from pre-EMT to now. Even if SST distribution does not strictly reproduce the surface circulation it can represent an interesting proxy to discuss some aspects of variability of the general circulation. An analysis of the interannual variability of the surface temperature field in the eastern Mediterranean Sea has already been described by Marullo et al. [1997] for the period 1984–1992. They found that the winter SST distribution in the Ionian Sea was essentially zonal for the period 1984–1990. From their analysis it results that the years from 1985 to 1990 show an overall zonal pattern of the isotherms suggesting that the Atlantic Ionian Stream (AIS) jet follows the typical path of the winter climatology, i.e., much closer to the southern boundary of the basin. In 1991 and 1992 they observed a winter SST pattern much more resembling the summer situation, with the warm water of the Gulf of Sirte spreading over the Ionian interior suggesting the presence of an overall anticyclonic tendency of the Ionian circulation.

Extending the Marullo et al. [1997] SST time series to the entire decade up to 2000 it appears evident that the “anomalous” winters 1991 and 1992 were in effect the first two years of a longer transient period that lasted until 1997. Figure 10 illustrates the Ionian winter SST distribution during the last four years of the decade, from 1997 to 2000. In 1997 the transient anticyclonic SST distribution is still present but since 1998 the SST field reverts to the 80’ picture described by Marullo et al. [1997]. In the years from 1998 to 2000 the SST distribution indicates that the warmer waters of the south Ionian tend to propagate...
northward in the eastern side of the Ionian Sea while the colder surface waters in northwestern Ionian Sea (probably of Adriatic origin) protrude southward on the western side suggesting the presence of a general cyclonic tendency of the circulation. This description also agrees with the recent results of Larnicol et al. [2002], which analyzed seven years of altimeter and SST data (from 1993 to 1999) on the Mediterranean Sea. In particular the Sea Level Anomaly (SLA) seasonal averaged maps in the Ionian Sea show a cyclonic circulation in the northern part of the basin developed after the 1997 and not evident before. In addition they demonstrated that the structure is strengthened in 1999, when the rest of the basin remains substantially unchanged.

In synthesis, the time series of the winter SST distribution in the Ionian Sea and the results of Larnicol et al. [2002] support the hypothesis of the presence of a cyclonic circulation until 1989 that switched to anticyclonic from 1990 to 1997, to return to a cyclonic pattern from 1998 onward. The intrusion of warm waters in the northern Ionian region, as a consequence of the winter anticyclonic regime of the surface layer, weakened the winter convective overturning in the years 1990–1997. After the EMT (i.e., after 1997), the reestablishment of the winter cyclonic circulation and the consequent cooling of the sea surface temperature in the area, facilitated a more efficient winter vertical mixing. Therefore, during EMT the weakened vertical mixing reduced the entrainment of nutrient to the surface layer, even if an uplifting of the nutricline due to the EMT was observed, while, after 1991, the hydrographic conditions of the basin became favorable to the injection uplifted nutrients in the upper layer.

4.3. How Much Did the Primary Production Increase in the CB Region?

To verify the impact of the CB on the productivity of the basin we attempted to estimate the Primary Production (PP) of the bloom in the two periods using SeaWiFS and CZCS images relative to the duration of the bloom (mid-February to late April), coupled with a simple light production model [Berthon and Morel, 1992]. The daily and depth integrated PP was derived through the following expression:

$$PP = \frac{1}{39} \cdot PSR$$

where $PSR$ is the daily photosynthetically stored radiant energy in the euphotic layer, and the conversion factor (39 kJ/g of fixed C) is taken from Morel and Berthon [1989]. $PSR$ is calculated using the Berthon and Morel [1992] formula:

$$PSR = \frac{PAR(0^+)}{Chl_{tot}} \cdot \psi^*$$

where (Chl$_{tot}$) is the chlorophyll content within the euphotic layer, estimated from satellite data using the relationship suggested by Berthon and Morel [1992]; PAR(0$^+$) is the daily Photosynthetically Available Radiation (PAR) just above the surface, and $\psi^*$ is the cross section for photosynthesis per unit of areal chlorophyll. PAR (0$^+$) was computed through the Gregg and Carder [1990] model, including Reed’s [1977] formula for cloudiness. $\psi^*$ was set to 0.07 following the results of Antoine and Morel [1996, Figure 2a].

A climatological CZCS-derived time series was produced from all the available pictures for the period of the bloom, extracting a 15 $\times$ 15 km box centered on the CB location and averaging chlorophyll values over cloud-free pixels. The larger number of available CB SeaWiFS scenes allowed the creation of time series separately for the years 1998 and 1999 over the same box as for CZCS.

Cloud cover data needed for the PAR (0$^+$) estimation were derived from European Center Medium Weather
Forecast (ECMWF) reanalysis data for the SeaWiFS years. Because of the unavailability of this information for the CZCS years we performed the PP assessment in the two cases of cloud cover equal to 0 and 100%.

The results of this analysis are summarized in Table 2 and show that even in the best, but unrealistic conditions of cloud cover always absent (0%), the estimate of PP for the CZCS years is lower than that for SeaWiFS years, performed with real cloud cover ECMWF data. The daily primary production estimated by the model amounts to 0.1–0.4 g/m²/d of carbon, which is very well within the range of what has been measured in the Sicily channel area.

Table 2. Model Estimation of Primary Production (PP) in the Calabrian Bloom Region From CZCS and SeaWiFS Chlorophyll Data at Different Levels of Cloud Cover

<table>
<thead>
<tr>
<th>Cloud Cover, %</th>
<th>Estimated PP, gC/m²</th>
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<tbody>
<tr>
<td>CZCS</td>
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<tr>
<td>Max</td>
<td>0</td>
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<tr>
<td>Min</td>
<td>100</td>
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<td>Average</td>
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<td>SeaWiFS 1998</td>
<td>ECMWF</td>
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<tr>
<td>SeaWiFS 1999</td>
<td>ECMWF</td>
</tr>
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by our group and in the western Ionian Sea by Moutin and Rainbault [2002].

5. Conclusions

[75] The necessarily coarse time and space resolution of in situ sampling in the EMED and, more specifically, in the Ionian Sea, precludes any reconstruction of the trophic evolution of the basin. Thus we tried to exploit the available remote sensing observations to inquire about the hypothesized enhancement of biological activity in the area due to the EMT. Two data sets relevant for our analysis derive from two different platforms with an obvious carryover of calibration and intercomparison problems. The two data sets have been independently validated with in situ observations, which makes them more reliable. As a matter of fact, most of the patterns and threshold values for biomass concentrations consistently coincide in the two time series. In our opinion, this makes any observed difference trustworthy.

[76] The Levantine basin did not appear to have been affected by the EMT, which is consistent with the existing analyses of the water property redistribution after the EMT. The Rhodes Gyre region was chosen as a test site and it resulted that the pre-EMT and post-EMT dynamics were basically the same, i.e., a dynamics driven by the convective events in a permanent cyclonic structure.

[77] Other areas of the EMED showed a very similar dynamics in the two periods considered. As already pointed out, this is probably the most important result of our analysis. Even in presence of large and dramatic change in the thermohaline circulation and in the distributions of nutrients, the biological activity of the epipelagos remained substantially unaltered. Our hypothesis, in agreement with previous suggestions from other authors, is that the EMT changed the intermediate and deep behavior of the basin, but was not able to affect the upper layer.

[78] By contrast, the pre-EMT and post-EMT patterns of biomass distribution in the northwestern Ionian Sea were different. Prior to the EMT there was an evident, though small, increase in chlorophyll concentration offshore the Calabrian coast, at the time of the spring bloom, with a consistent onshore-offshore gradient, probably fed by upwelling events and/or land runoff. After the onset of the EMT a recurrent and large bloom was detectable, which encompasses a wide area of the northwestern Ionian Sea. This bloom did not accumulate large quantities of biomass (chlorophyll up to 0.8 mg/m²) but was a novel feature of the basin. An in-depth analysis of the existing data strongly suggests that the CB was linked to the changes due to the EMT because, without the uplift of nutricline caused by the EMT, the nutrients needed to sustain a bloom would have been unavailable. Furthermore, our analysis suggests that a series of concurrent factors such as doming and convection were present to favor the transport of nutrients to the photic zone and that this occurred only in particular restricted areas. For what concerns the overall budget, the structure seems to have enhanced the primary production by a factor from 1.4 to 2.8.

[79] In conclusion the EMT did not affect the surface biological dynamic of the EMED, principally because the uplifted nutrients remained in layers that cannot be reached with the typical forcing of the area, except for the western Ionian Sea. On the other hand it is not possible with our data to exclude subsurface (i.e., changes in the Deep Chlorophyll Maximum dynamic) or purely biological effects (i.e., changes in trophic chain), that can have important consequences on the total biological dynamics of the basin.

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